

Dc machines

①

I. Theoretical questions

Q1 : Draw the construction of a Dc machine showing its components.

Q2 : What is the role of commutator & brushes in Dc machines.

Q3 : Derive the emf equation (E_a) in Dc machines

Q4 : show the relation between ϕ_e & ϕ_p , then, Derive an expression relating the frequency (f_e) to the mechanical speed (n)

Q5 : show flux distribution in Dc machines.

Q6 : Describe the operation of Dc machine as a generator & as a motor

Q7 : Draw the circuit diagram of (2) DC generators, then show why the external c/c's of shunt DC generator is more drooping than separately excited.

Q8 : Draw the circuit diagram of various types of DC motors.

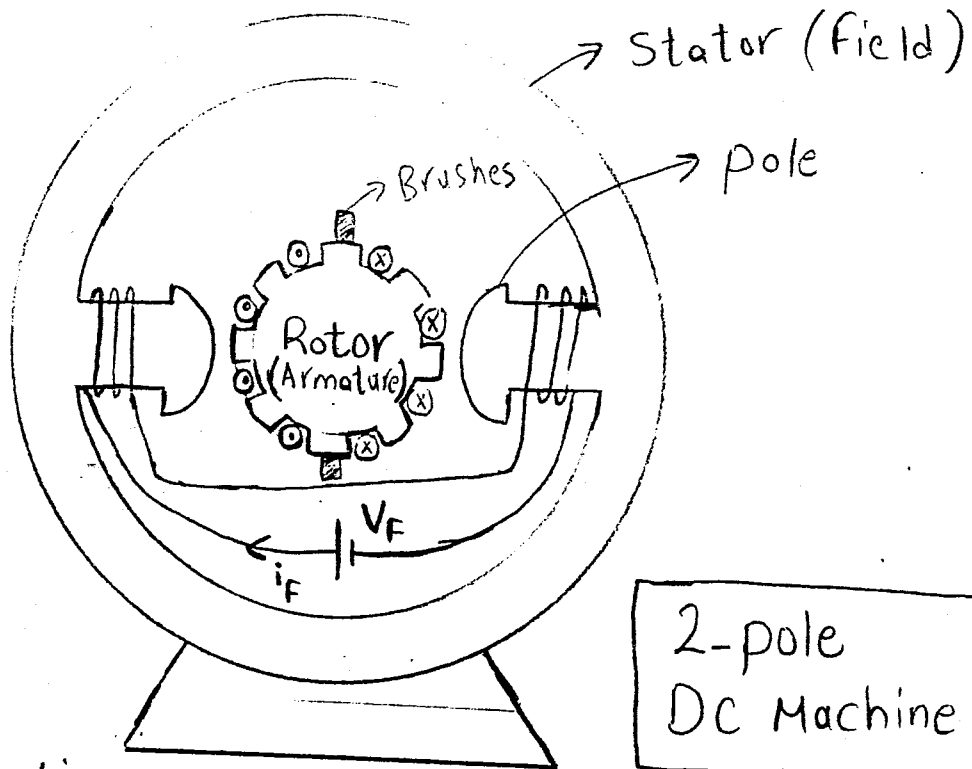
Q9 : What is the significance (role) of back emf in DC machines.

Q10 : Why is the starting current is high in DC machines, How to limit this current.

Answer of Q1

3

Dc Machines



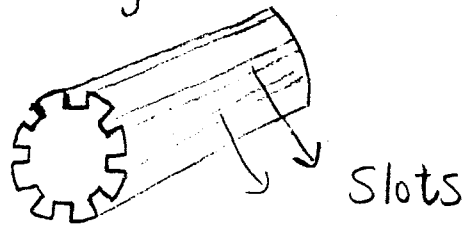
Construction

① Stator

- Carries the field winding (exciter)
- Field winding is connected to DC Voltage source
- Field winding produces the magnetic flux.

② Rotor

- Carries armature winding
- Rotor has a cylindrical shape with slots
- The conductors are placed in these slots.
- e.m.f is induced on the terminals of armature winding.



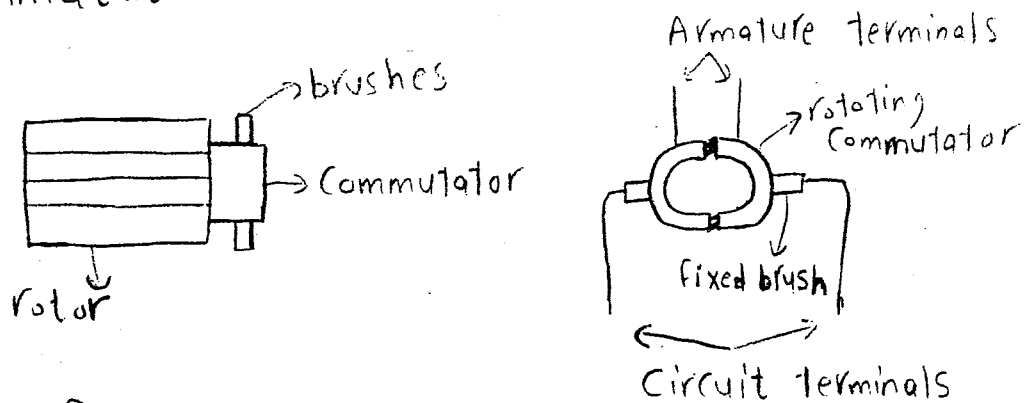
- Rotor is laminated to reduce eddy losses.

③ Commutator

- * It's a copper cylinder divided into isolated segments
- * It's connected to armature winding terminals
- * It's a rotating part.

④ Carbon brushes

- They are fixed contacts
- They are in direct contact with the commutator



⑤ Air gap:

- It's the clearance between stator and rotor

Answer of Q2

Notes

- (a) commutator is used to
- convert AC voltage to DC voltage in case of DC generator
 - produce unidirectional torque in DC motor

- (b) The horizontal axis is called pole axis,
The vertical axis is called interpole axis.

Answer of Q3

⑥

The Flux linkage of armature conductor:

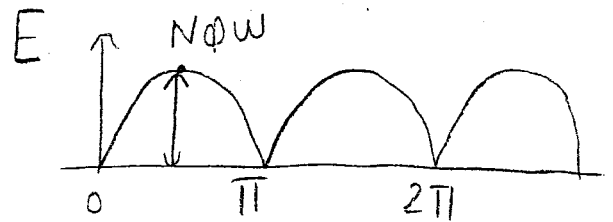
$$\lambda = N\phi \cos \omega t$$

$$\text{but } e = -\frac{d\lambda}{dt} = +N\phi \omega \sin \omega t$$

* The commutator produces DC voltage

$$\therefore E_a = \frac{2 N\phi \omega}{\pi}$$

↓
average
armature
Voltage



$$\therefore E_a = k n \phi$$

$$E_a \propto n \phi$$

$$\text{But } \phi \propto I_f$$

$$\therefore E_a \propto n I_f$$

$$\text{If } I_f = 0 \Rightarrow E_a = 0$$

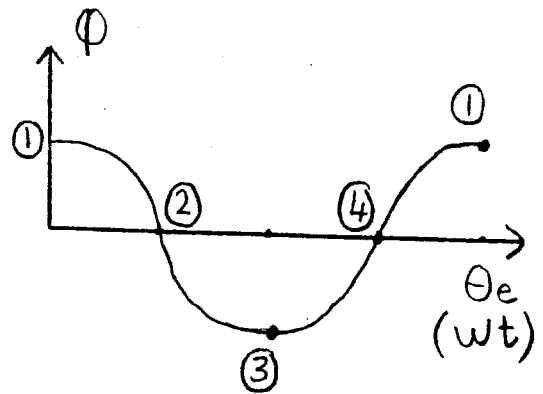
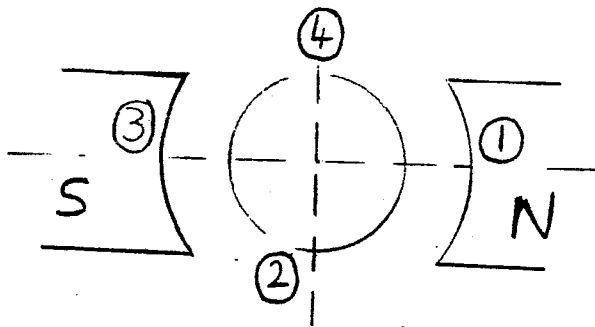
$$\text{If } n = 0 \Rightarrow E_a = 0$$

Relation between Θ_e , Θ_m

$\Theta_e = \omega t$; ω is electrical angular frequency

$\Theta_m = \omega_m t$; ω_m is mechanical angular frequency

For 2 poles ($\overset{\text{no. of pole pairs}}{P=1}$)



① → ②

$\Theta_m = 90^\circ$

$\Theta_e = 90^\circ$

② → ③

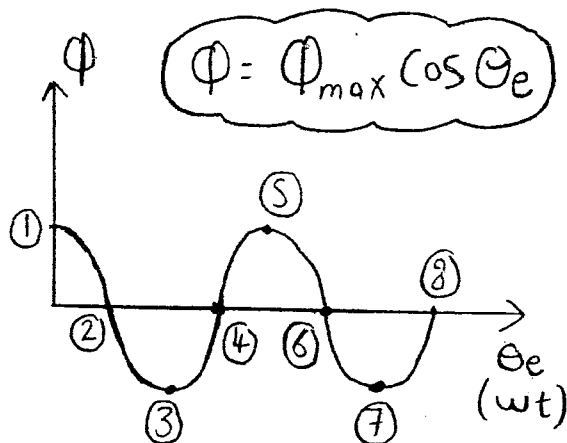
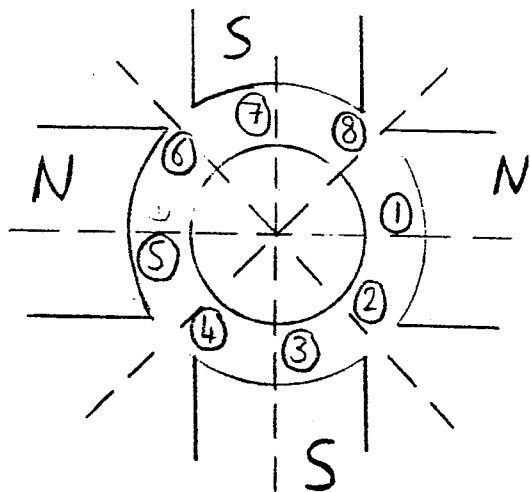
$\Theta_m = 90$

$\Theta_e = 90$

$$\therefore \Theta_m = \Theta_e$$

For 2 poles

For 4 poles ($p=2$)



$$\left. \begin{array}{l} ① \rightarrow ② \quad \theta_m = 4S \quad \text{but} \quad \theta_e = 90^\circ \\ ② \rightarrow ③ \quad \theta_m = 4S \quad \text{but} \quad \theta_e = 90^\circ \end{array} \right\}$$

$$\therefore \theta_e = 2\theta_m$$

\therefore For (p) poles

$$\theta_e = p \times \theta_m$$

$$\therefore \omega_e = p \omega_m$$

hence

- When $p=1 \Rightarrow \theta_e = \theta_m$, $\omega_e = \omega_m$
- When $p=2 \Rightarrow \theta_e = 2\theta_m$, $\omega_e = 2\omega_m$

Relation between f_e & n_m

9

$$\therefore \theta_e = p \theta_m$$

$$\therefore \frac{d\theta_e}{dt} = p \frac{d\theta_m}{dt}$$

$$\omega_e = p \omega_m$$

$$\therefore 2\pi f_e = p \times 2\pi f_m$$

$$\therefore f_e = p f_m$$

$$\text{But } f_m = \frac{n}{60}$$

Where n : Number of revolutions per minute (rpm)

$$\therefore f_e = \frac{pn}{60}$$

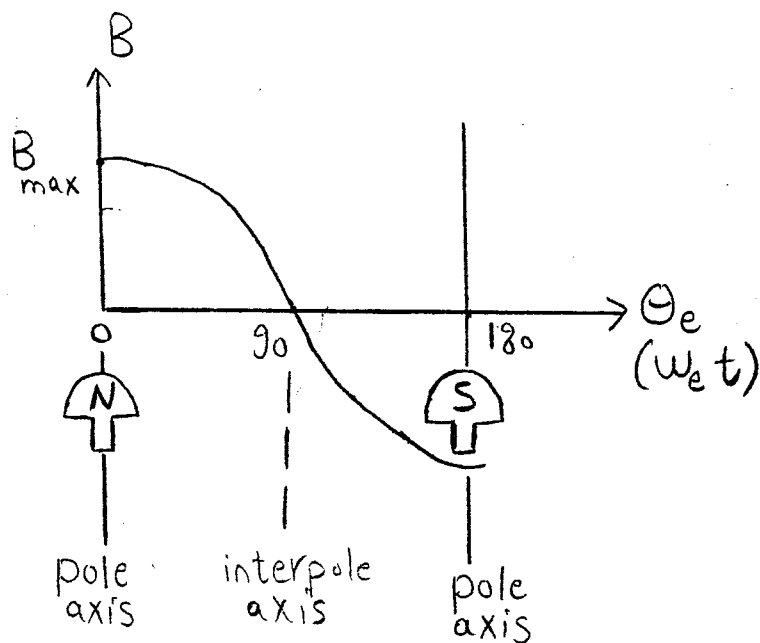
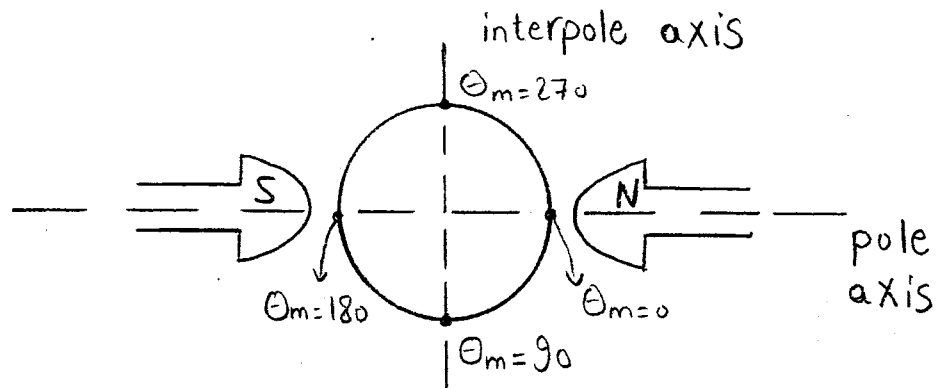
f_e : electrical frequency (Hz)

p : Number of pole pairs

n : Mechanical speed of rotor in rpm

5'

Flux density distribution in DC machine
[Flux of stator]



$$B = B_{\max} \cos(\omega_e t)$$

This means that the Flux varies sinusoidal

Dc machine can operate as

① Dc generator

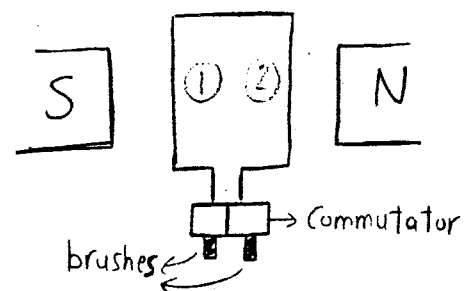
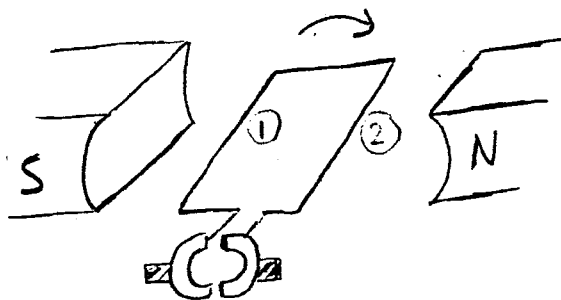
② Dc motor

① Dc generator

Theory of operation

(a) The field current produces Flux

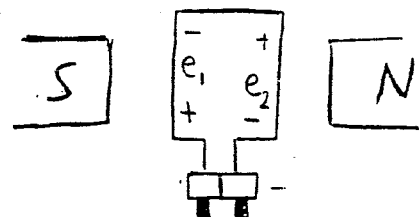
(b) IF the rotor (armature coil) is externally rotated



(c) A Voltage will be induced on both conductors (1,2)

$$e_1 = BLV \quad e_2 = BLV$$

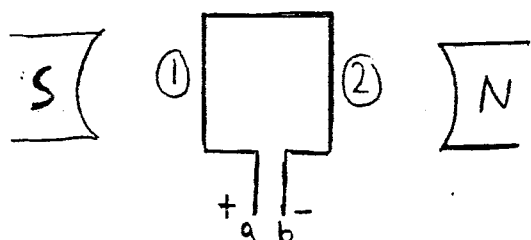
$$e_{\text{coil}} = 2BLV$$



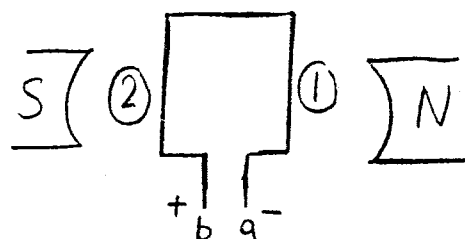
(d) The Commutator Converts Ac Voltage into Dc.

Why do we use Commutator & brushes

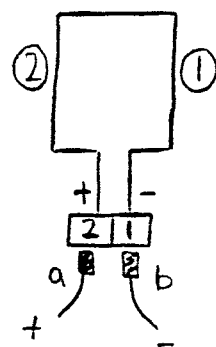
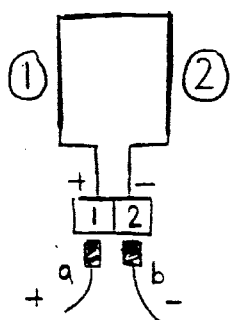
In First half cycle
of the coil rotation



In Second half cycle
of the coil rotation



The voltage across the coil changes its polarity, So we use Commutator and brushes as a mechanical rectification to get DC voltage from the coil

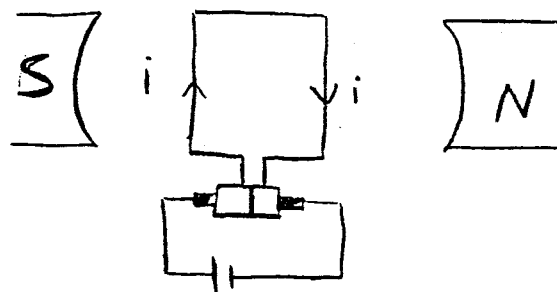


* brush (a) is +ve in both half cycles
brush (b) is -ve " " " "

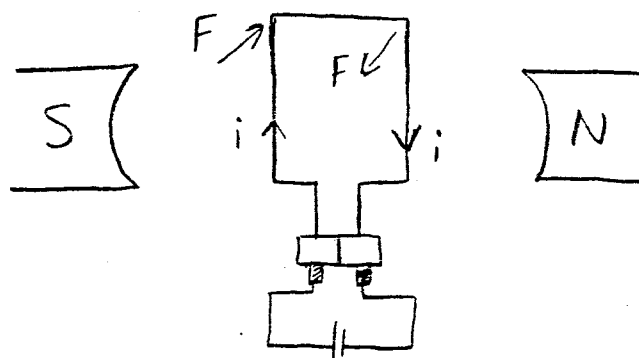
② DC motor

Theory of operation

- (a) The field current produces Flux
- (b) IF the armature winding terminals are connected to an external DC Source, then a current will flow in armature winding.



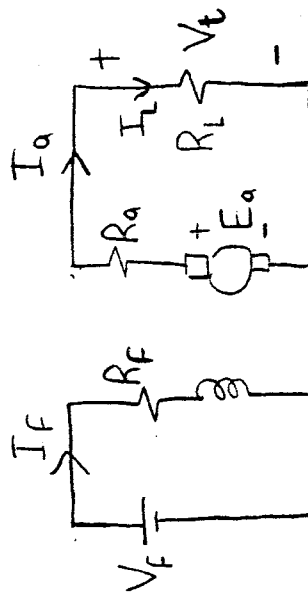
- (c) Now both conductors (1,2) has a current i and placed in a magnetic field (B), so A Force will be produced on both conductors but in opposite direction. ($F = BIL$)



- (d) So, the coil starts to rotate with a torque $T = BILW$
- (e) As the coil rotates in a magnetic field, so a back emf will be induced on the coil (as in generator)
- (f) The commutator converts the torque into unidirectional torque

Types of DC generators

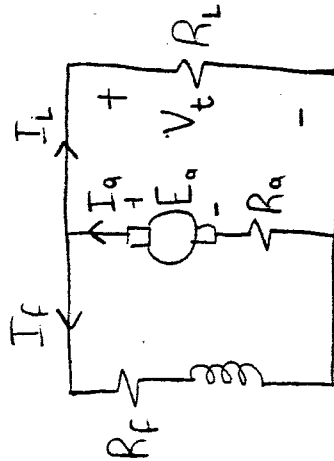
I Separately excited



$$V_f = I_f R_f$$

$$E_a = V_t + I_a R_a$$

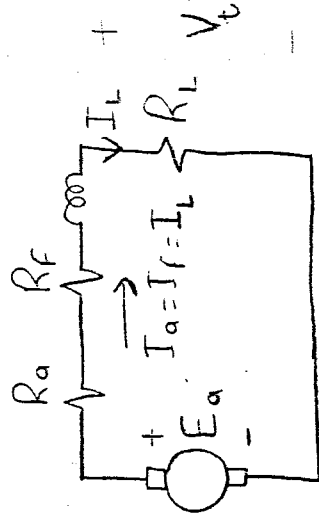
II Shunt



$$I_f = \frac{V_t}{R_f}$$

$$E_a = V_t + I_a R_a$$

III Series



$$E_a = V_t + I_a (R_a + R_f)$$

$$I_a - I_L = I_f$$

Answer of Q7

15

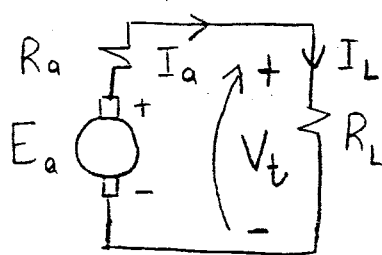
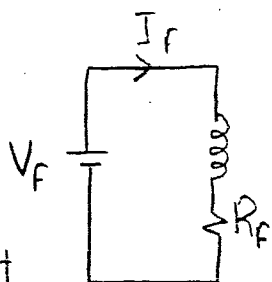
I Separately excited DC generator

⇒ Field circuit

$$V_f = I_f R_f$$

* $I_f \rightarrow$ Field current

* $R_f \rightarrow$ field resistance



⇒ Armature circuit

$$E_a = V_t + I_a R_a + (\text{Armature reaction drop})$$

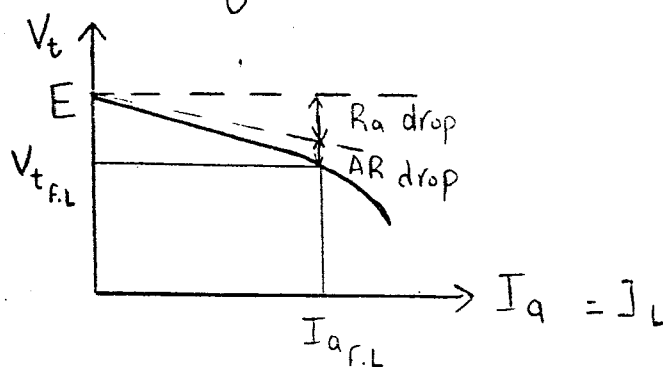
* $R_a \rightarrow$ Armature resistance

* $I_a \rightarrow$ Armature current

* $V_t \rightarrow$ Terminal Voltage

IF (AR) is neglected $\Rightarrow E_a = V_t + I_a R_a$

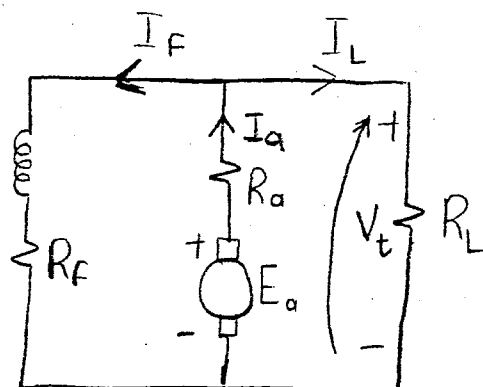
⇒ External characteristic of separately excited DC generator



II Shunt DC generator

$$I_f = \frac{V_t}{R_f}$$

$$E_a = V_t + I_a R_a$$



The voltage drop is due to

- ① R_a drop.
- ② Armature reaction drop
- ③ Decrease in field current

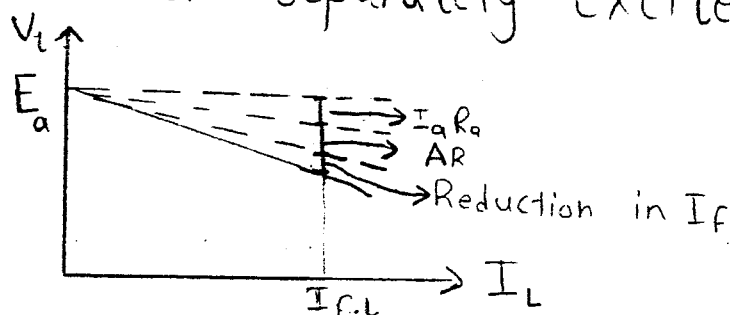
as $I_f = \frac{V_t}{R_f}$ (V_t decrease as I_L increases)

$$\therefore I_f \downarrow \rightarrow \Phi \downarrow \rightarrow (E_a = k n \Phi) \downarrow \rightarrow V_t \downarrow$$

That's why shunt DC generator has external C/C's which is more drooping

than that of separately excited' (عشان sep. excited
بجمله اول نوعين
من ال drop فقط)

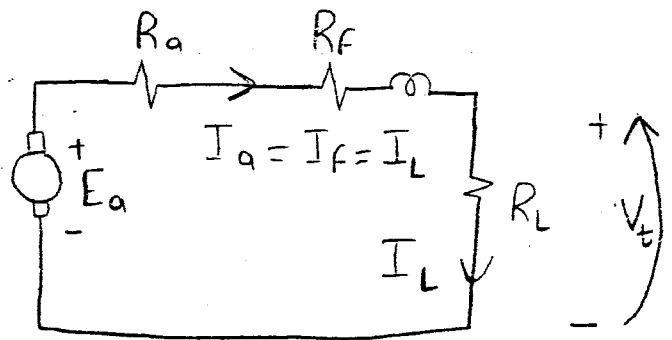
External
C/C's



III Series DC generator

$$I_a = I_f = I_L$$

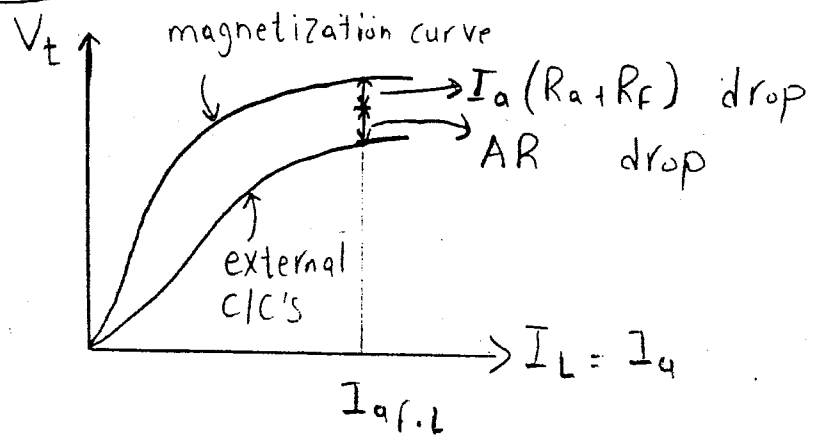
$$E_a = V_t + I_a(R_a + R_f)$$



The Voltage drop is due to

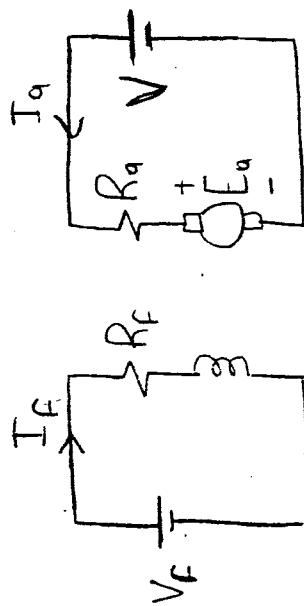
- ① $(I_a R_a + I_a R_f)$ drop
- ② AR drop

External C/C's



Types of DC motors

I Separately excited



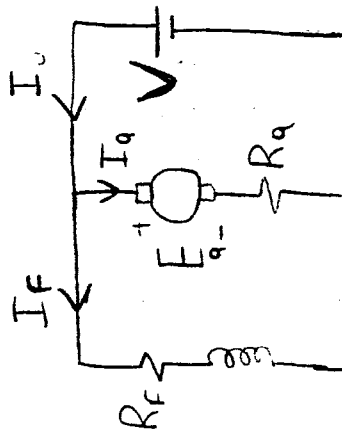
$$V_f = I_f R_f$$

$$E_a = V - I_a R_a$$

$$E_a = k n \Phi \Rightarrow E_a \propto n I_f$$

$$T = k I_a \Phi \Rightarrow T \propto I_a I_f$$

II Shunt



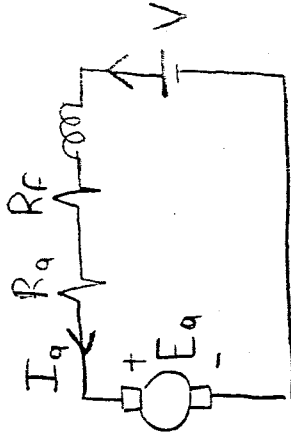
$$I_f = \frac{V}{R_f}$$

$$E_a = V - I_a R_a$$

$$E_a = k n \Phi \Rightarrow E_a \propto n I_f$$

$$T = k I_a \Phi \Rightarrow T \propto I_a I_f$$

III Series



$$E_a = V - I_a (R_a + R_f)$$

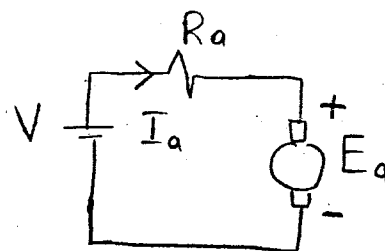
$$E_a = k n \Phi \Rightarrow E_a \propto n I_a$$

$$E_a \propto n I_f$$

$$T = k \Phi I_a \Rightarrow T \propto I_a^2$$

Role of back emf (E_a) in motors

E_a produces a current opposite to the supply current, so the armature current is limited within acceptable range



Starting of DC motors

⇒ Answer of Q 10

$$\therefore V = E_a + I_a R_a$$

$$\therefore I_a = \frac{V - E_a}{R_a} \quad \text{but } E_a = K n \phi$$

But at starting ($n=0$) $\Rightarrow E_a=0$

$$\therefore I_a|_{st.} = \frac{V-0}{R_a} \uparrow\uparrow \text{ (Very high)}$$

\therefore The armature current is very high at starting, so we must use starters (starting resistors to reduce $I_a|_{st.}$)

II. problems

(21)

Laws

$$\textcircled{1} \quad \omega = \frac{2\pi n}{60} \rightarrow \text{rpm}$$

\downarrow
rad/s

$$\textcircled{2} \quad E = K \phi \omega \rightarrow \textcircled{a}$$

But $\phi \propto I_f$, $\omega \propto n$

$$E = K_1 \phi \cdot n \rightarrow \textcircled{b}$$

$$E = K_2 I_f n \rightarrow \textcircled{c}$$

$$\textcircled{3} \quad T = K \phi I_a \rightarrow \textcircled{a}$$

$$T = K' I_f I_a \rightarrow \textcircled{b}$$

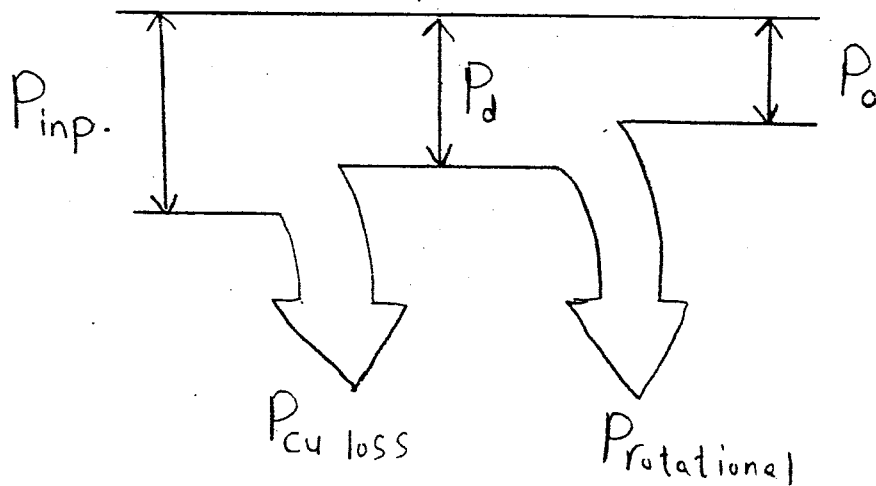
$$T_d = \frac{P_d}{\omega} \rightarrow \textcircled{c} \quad (T_d: \text{developed torque})$$

$$\textcircled{4} \quad T_o = \frac{P_o}{\omega} \quad (T_o: \text{output or shaft torque})$$

$$P_o = P_d - P_{\text{friction}}$$

$$\textcircled{5} \quad \begin{aligned} \text{IF } E > V_t &\rightarrow \text{generator} \\ \text{IF } E < V_t &\rightarrow \text{motor} \end{aligned}$$

power flow in DC motor



* $P_{inp} \equiv \text{input power} = V_s I_{inp.}$ \rightarrow input current

* $P_{cu \text{ loss}} = I^2 R$ (depends on connection)

* $P_d \equiv \text{developed power} = E_a I_a = T_d \omega_m$

* $P_r \equiv \text{rotational loss}$

* $P_o \equiv \text{output power} = T_{sh} * \omega_m$
 \downarrow
 shaft torque

$$\eta = \frac{P_o}{P_{inp.}} = \frac{P_{inp.} - \sum \text{losses}}{P_{in}}$$

* $P_o = P_d - P_{rotational}$ * $P_d = P_{in} - P_{cu \text{ loss}}$

14 Series motor
sheet

$$R_a = 0.5 \Omega, R_f = 1.5 \Omega$$

$$I_a = 20 \text{ A when } n = 1200 \text{ rpm}$$

$$V = 220 \text{ V}, P_{\text{rotational}} = 150 \text{ W}$$

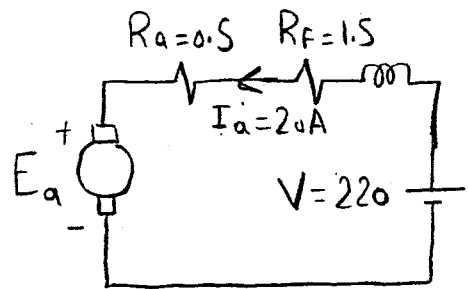
Find P_o, η

Solution

$$E_a = V - I_a(R_a + R_f)$$

$$E_a = 220 - 20(0.5 + 1.5)$$

$$\therefore E_a = 180 \text{ V}$$



$$\Rightarrow P_o = P_d - P_{\text{rot.}}; P_d = E_a I_a = 3600 \text{ W}$$

$$P_o = 3600 - 150$$

$$P_o = 3450 \text{ W}$$

$$\Rightarrow P_i = V \times I_a = 4400$$

$$\Rightarrow \eta = \frac{P_o}{P_i} = \frac{3450}{4400} = 78.4\%$$

$$\eta = 78.4\%$$

Sheet (15) • Dc motor (Assume separately excited) (24)

• at No load: $V = 100V$, $n = 1200 \text{ rpm}$

• $R_a = 2\Omega$

• Find T, I_a if $V = 220V$, $n = 1500 \text{ rpm}$

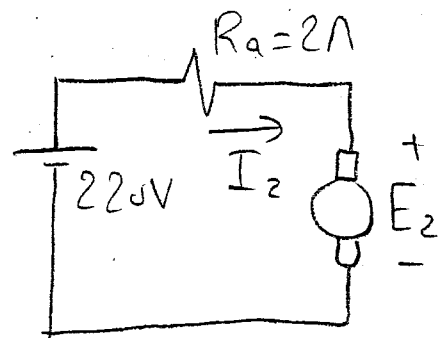
• I_f is Constant

Solution

Case ① $V = 100V$
 $n_1 = 1200 \text{ rpm}$
No load ($I_a \approx 0$)

$$E_1 = 100V$$

Case ② $V = 220V$
 $n_2 = 1500 \text{ rpm}$



$$\ast \frac{E_2}{E_1} = \frac{n_2}{n_1}$$

$$\frac{E_2}{100} = \frac{1500}{1200} \Rightarrow E_2 = 125V$$

$$\ast E_2 = 220 - 2I_2 \Rightarrow I_2 = 47.5A$$

$$\ast P_d = E_2 I_2 = 5937.5W$$

$$\ast T_d = \frac{P_d}{\omega} = \frac{5937.5}{2\pi \left(\frac{1500}{60}\right)}$$

$$T_d = 37.8 \text{ N.m}$$

16) Sheet

• DC Shunt motor

• Constant field ($I_f = \text{Const.}$)

• $T \propto n$

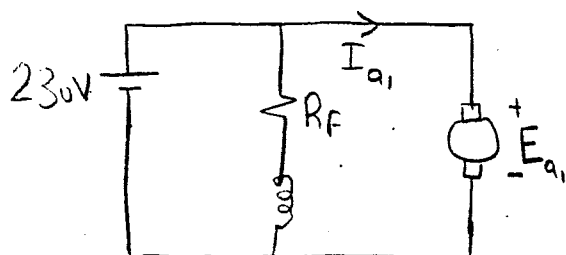
• $I_a = 30\text{A}$ when $n_1 = 750\text{ rpm}$

• $R_{\text{series}} = 10\ \Omega \Rightarrow n_2 = ??$

• R_a is neglected

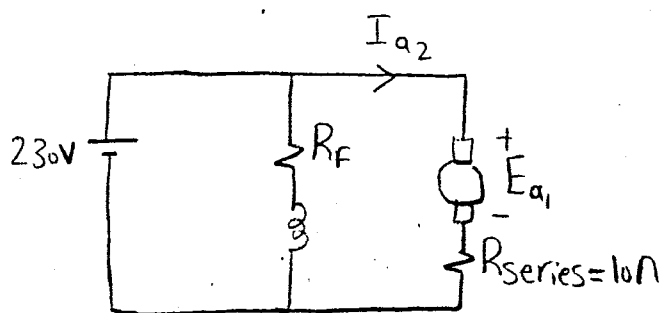
Solution

Case ① $n_1 = 750\text{ rpm}$
 $I_{a1} = 30\text{A}$



$$E_{a1} = 230\text{V}$$

Case ② $R_{\text{series}} = 10\ \Omega$



$$E_{a2} = 230 - 10 I_{a2}$$

\Rightarrow But $E \propto n \phi \xrightarrow{\text{Constant}} E \propto n$

$$\therefore \frac{E_2}{E_1} = \frac{n_2}{n_1}$$

$$\frac{230 - 10 I_2}{230} = \frac{n_2}{750}$$

$$0.306 N_2 + 10 I_2 = 230 \rightarrow (1)$$

\Rightarrow But $T \propto n$ (given)

$$T \propto \underset{\substack{\uparrow \\ \text{const.}}}{\Phi} I_a \Rightarrow T \propto I_a$$

$$\therefore \frac{T_2}{T_1} = \frac{n_2}{n_1} = \frac{I_2}{I_1}$$

$$\therefore \frac{n_2}{750} = \frac{I_2}{30}$$

$$\therefore n_2 = 25 I_2 \rightarrow (2)$$

Solving (1), (2) we get

$$I_{a2} = 13 \text{ A}$$

$$n_2 = 325.7 \text{ rpm}$$